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Modeling of the potential fields transformants for the ring structure Illinetska

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SUMMARY

The purpose of the thesis is to present some notes on new results of guided interpolation for the gravity field and its gradient transformants due to Illinetska circular tectonic structure. The structure has numerous outcrops and wells to study the impact metamorphism of minerals in a crater. However, they didn't reach the crystalline base, only the crust, so the reliability of the explosive structures and the central uplift is poor. The geological structure and genesis of the Illinetska structure were unclear. Their impact or volcano origin is discussed. This study clarifies the reliability of previous studies.

We calculate the vertical and/or gravity horizontal gradient module and compare it with the observed gravity in Bouguer reduction within the area studied. Choosing the properly an interpolation techni¬que and to adjust its parameters truly, we obtain a series of 3D surface sketches with minimal distorti¬on by kriging and modified Shepard's techniques in the Golden Software Surfer. Pairwise comparison of gridding techniques on simulated gravity data allows us to produce reliable contour maps of inter¬preted output.

Results of the application of this technique to the initial gravity data for the central part of Illinetska structure are presented. There is shown that the transformant intensifies the central part of the gravity anomaly, where the boundaries of the structure sharply appeared. The impact hypothesis of the origin of the Illinetska structure was additionally justified, and the position of ejection cone is tuned.

Practical value of the interpretation is that the Illinetska structure by the gravity field transformants simulated indicate a periodic wavy nature of the destruction of its rocks and the preliminary explosion energy is estimated by 6.15×1015 J.

Introduction. The Illinetska circular tectonic structure is located 10 km west of the village of Illintsi, Vinnytsia region in the Valley of Sibok River, within Volyn-Podilsky crystalline massif. Until the 19-70s, it was considered a Silurian-Devonian volcano. Later, rocks showed some signs of shock metamorphism; it was considered an astrobleme (Nikolsky, 1975). In 1979, the Pravoberezhna Geological Expedition discovered diamonds typical for meteorite craters, with lonsdaleite included.

The structure has outcrops (6 units) and wells (55 units), which is a testing ground to study the *impact* metamorphism of minerals and the formation of craters. At least, half of the wells did not reach the crystalline base, they stopped within the crust. The western part of that structure has not been studied; the reliability of the explosive structures and the central uplift is *poor*. In 2010, 3 wells were drilled on the structure (from 121.1 to 140.3 m depth) and the areal magnetic exploration 50×50 m was performed, thus the geological structure and genesis of the Illinetska structure were clarified. The view of its impact origin dominates (Walter and Ryabenko, 1976), but the limits of hidden rock complexes and the mechanism of its formation have no appropriate studies. This study clarifies the reliability of previous constructions (Gurov and Gurova, 1991).

Previous geological and geophysical observations. Geological and geophysical features of the Illinetska structure and the corresponding maps are described in (Entin et al., 2013). In the gravity field, this structure has a minimum amplitude of **6.5** mGal ovals 6×7 km sized of the northwestern strike. The minimum exceeds the area of distribution of impactites, due to the influence of the zone of fractured cataclastic rocks of the crystalline basement. On the map of the gravity horizontal gradient, the minimum has a concentric-zonal structure, such as 2-5 rows of the concentric chains or fragments of zones of low values of intensity (**20-40** E). As the simulation showed, they are formed due to the imposed gravity effect from the decompression of crystalline rocks within the tectonic zones of the ring neck. A number of signs indicated a significant asymmetry in the features of its structure and heterogeneity of its internal structures (Entin et al., 2013).

The magnetic field of the structure is calm, negative (–**400** ÷ –**600** nT). The external contour of the structure does not appear in it, while in the central part there are a number of local minima, we especially emphasize 2 intense extrema with amplitudes of **1000** and **700** nT. They form a two-humped negative anomaly of 350×150 m, that coincides with an intense local minimum of gravity. This is an *ultrahigh-gradient* magnetic minimum, which is a *unique* item for impacts of the world. Illinetsky crater is the oldest eroded one on the Ukrainian shield. Its size is ~4×5.5 km; the diameter of the crushed rock zone is ~7 km. In the section, *four* rock complexes are distinguished: basement, coptogenic, and filling and overlapping complexes. At the bottom of the crater, there are rocks of the basement complex (authigenic, unbroken breccia from Archean-Early Proterozoic rocks of the same composition as in the rim of the structure). With depth, the signs of shock metamorphism fade.

The coptogenic (created by the explosion) complex is an allogeneic (displaced) breccia, lies on authigenic (autochthonous) rocks of impactites. Impactites complete the top of the coptogenic complex, depending on the glass content, they are divided into zuvites (10-75% of glass) and tagamites (dense strong rocks, up to 90% of glass, they are lonely differently oriented lenses with a thickness of **0.04-46.4** m) in areas close to contact with brecciated foundation). Among these brocks, allogeneic breccia predominates.

The bottom of the structure (between authigenic and allogeneic breccia) has an oval saucer shape, with a stock-like central elevation ~70 m high and ~500 m in diameter (a sign of meteor craters). Around the central uplift, there is a peripheral ring depression 300-400 m wide and 50-80 m deep. Another depression is in the latitudinal direction from the central uplift to the east (30-70 m deep, 300-600 m wide). The rise of 200×400 m wide and of 30-40 m height in the east of the structure correlates with the deepening of the bottom of the latitudinal basin. A structural feature is the subhorizontal tagamite layer with a thickness of 35 m in the southern part.

Lenses of Devonian mudstones and deluvium (a cemented weathered mass of disintegrated zuvites, fragments of mudstones, brecciated basement rocks) overlie the rocks of the coptogenic complex. One

of the 3.7 km long mudstone lenses is oriented latitudinal, filling the ancient hollow. To the east of the central uplift, the Devonian mudstones are overlain by zuvitic deluvium, clays (thickness up to 50 m) of Carboniferous age. These rocks are the filling complex, its maximum thickness is ~162 m. Above the filling complex are the Neogene secondary kaolins, clays, sands, Quaternary deposits; these are the overlapping complex. Its average thickness on the watershed (the center of the structure) is ~13 m; in the Valley of Sibok River, it is ~0-3 m. The basement complex of brecciated rocks in the modern erosion section (area ~6×4.5 km, width from the boundaries of impactites is ~1-1.7 km, oval to the northeast) according to the composition of authigenic breccia corresponds to the composition of the underlying rocks of the basement and is described (Entin et al., 2013). The transition between rocks and breccia is gradual. The depth of shock decompression of the basement rocks under the Illinetska structure at the level of the modern erosion section is ~1 km, while at a meteorite falling time it is estimated ~2 km. This coincided with the results of our simulation.

The coptogenic complex of the Illinetska structure is an annular lens of complex structure and morphology of the surface and the bottom (allogeneic breccia, zuvites and tagamites). Allogeneic breccia occurs with a gradual transition to authigenic breccia, filling the annular groove of ~4 km in diameter. Breccia composition is a complex of fragments of rocks (50-90%) and minerals (15-50%), glass (0-7%). Rock fragments are granites, gneisses, crystal schists, amphibolites, the inclusion of siltstones and sandstones, there are blocks of siltstones up to 18 m. The boundaries of allogeneic breccia correspond to the boundaries of the Illinetska structure. Due to the *gradual* transitions with the neighbors in the section and the description of the wells in the terminology of volcanics, the average thickness of this breccia is not determined, it is approximately ~10-20 m. Upward along the section, the size of the fragments in the breccia gradually decreases, zuvites appear (strong breccia rocks, porous, cavernous, with broken glass). In the outcrops, zuvites are fractured and horizontally tiled. The fragments of pre-impact mudstones in thin sections are ~2 cm, rounded and oval in shape, color varies from dark gray to dark brown and *wavy* texture.

The glass content in zuvites is ~10-45% in the lower horizon and ~60-75% in the upper one. According to (Gurov and Gurova, 1991), the pulse pressure of mineral transformations is ~**40-50** GPa, and shock temperatures are ~**1500** °C. All minerals have signs of shock metamorphism (Walter and Ryabenko, 1976). The orientation of the angles between the poles of the planar element and the optical axis of quartz indicate a shock at a peak pressure of ~**16–20** GPa. The main differences of the zuvites from their volcanic analogs (tuff, tuff breccias) are signs of shock metamorphism and the discovery of lonsdaleite-containing diamonds. The maximum thickness of the zuvite lens in the center of the structure is ~100 m, the average one is ~30-50 m.

Tagamites are strong glassy massive rocks of black color, after weathering brown-brown, having 90% of the glass content of afanite structure. By thickness they are divided into 3 groups: 2-50 cm; 5-13 m; 30-35 m. The reason for the *discreteness* is unknown. Tagamites are distributed in 3 parts of the structure: center (on the slopes of the uplift), east (among the zuvites of the eastern depression with mudstones), and south. Tagamite lenses fall sharply in the center, form oval lenses in the east and a subhorizontal stratum in the south. The stratum has **2** blocks, the eastern one is raised relative to the western one (20 m in the north, 40 m in the south). The western "key" has a *bias* to the southeast; while eastern do so to the north. The boundaries of the "tagamite plate" have not been studied. According to the model, they are sharp and limited by faults. Parts of the plate *repeatedly* moved vertically in the era of late tectonic activations. A plate is a fragment of an annular lens around a central uplift.

Methods of investigation. The results of the interpretation of individual elements of the geophysical fields of the Illinetska structure (and its Surfer + Voxler representation) are given below. According to the ideas about the region's structure and density distribution, we adopted a *gradient-layered* model of density increase with depth, taking into account the presence of zones of constant density values. The separation of density inhomogeneities in the construction of the first approximation model we carried out according to the initial gravity field (the Bouguer reduction) and maps of its transformants, especially the horizontal gradient (Figure 1). Transformants of the gravity field *emphasized* the features of field observed data.

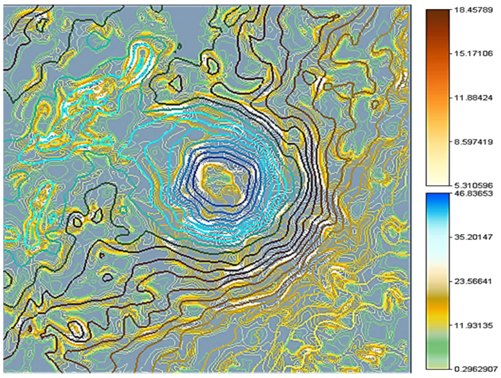

***Figure 1**. Superposition of the observed gravity field (yellow-brown palette) and the module of its horizontal gradient (green-blue palette)*

The discussion of the results. The transformant intensified the central part of the anomaly in the field of the gravity gradient modulus, where the boundaries of the central part of the structure sharply appeared. If the meteorite hypothesis of the origin of the Illinetska structure is true, then in the picture of the field of the gravity horizontal gradient module (GHGM) in its upper left part a ravine anomaly appears that can fix the position of the ejection cone formed because of the impact event (Figure 2).

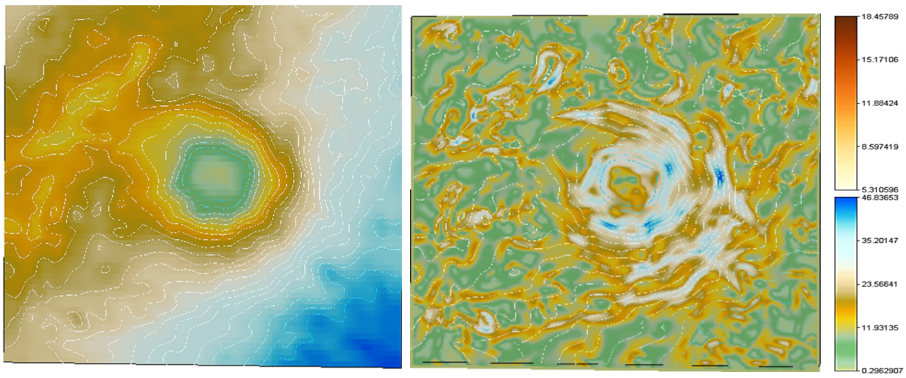

***Figure 2**. The observed gravity field (left) and the modulus of its horizontal gradient (right)*

These models (Figure 2) emphasize a smooth density distribution within the Illinetska tectonic structure. Clear contours indicate the absence of additional dislocations and disturbances (faults) in the structure. Since its inception, the Illinetska structure has been acting in the field of tectonic stresses as an established structural complex. A concentric structure appeared in the field of the gravity horizontal gradient module (Figure 3). The intensity of the palette reflects the correlation of rock complexes having similar physical properties. The zuvite complex (raspberry color) has an expressive concentric structure, indicates the periodic nature of the shock effect on the rocks, similar to a blasting wave.

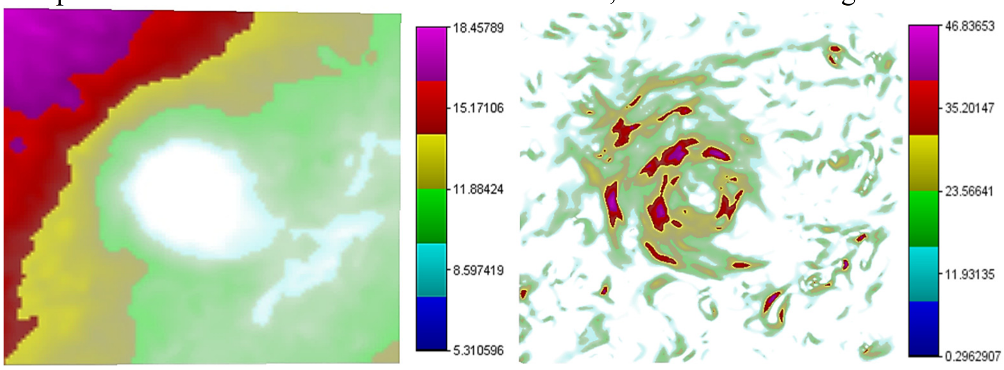

***Figure 3**. Continued upward by 1 km observed gravity field (left, wave-like propagation of the destruction front) and the field of its horizontal gradient modulus (right)*

Conclusions. Visualization (Figure 4) of 3D models of the gravity field and the modules of its horizontal gradient fixes the possible propagation front of rock destruction and zonal separation of lithological complexes. This confirms the periodic nature of the explosion; the explosive action propagated as a wave, and not as an instantaneous impulse.

2D / 3D models of that anomalous structure by the gravity field confirmed the impact genesis of the Illinetska structure. The main explosion energy of the impact event fell on opposite sides of the structure (northern and western). The explosion energy is preliminarily estimated at **1.47** Mt in TNT equivalent, i.e. E ≈ $\mathbf{6.15 \times 10^{15}}$ J with an average meteoroid density of ~500 kg/m^3, a diameter of ~40 m and a mass of ~0.1 Mt. The picture of the event according to the simulation of magnetic fields is unambiguous and requires additional coordination with the data of mineralogy.

The Illinetska structure has a long (~50 million years) multi-stage development. Petrography data confirm the impact nature of zuvites and breccia. But the enrichment of impactites with chromite, the chemistry of tagamites, paleomagnetic data and the structure of the bottom deny the implicit genesis of the Illinetska structure. The prospect of detailed studies of the structure lies in its comprehensive study by complex of geophysical methods.

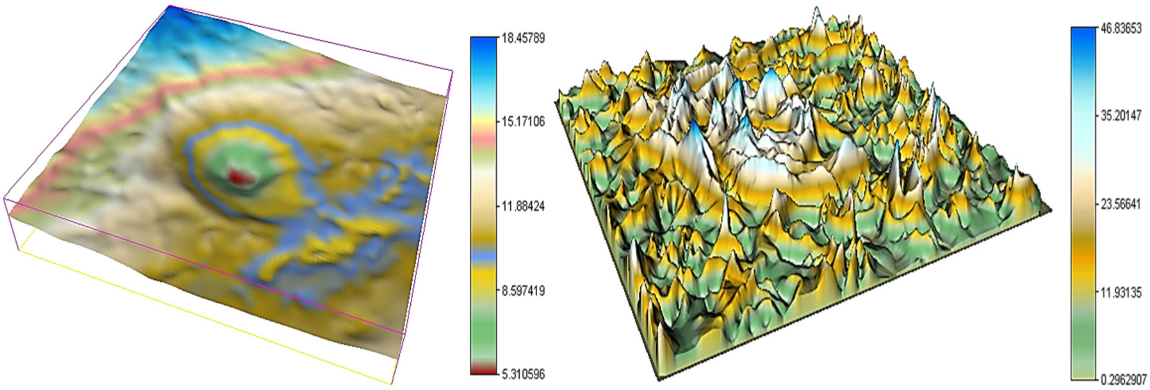

***Figure 4**. 3D model of the observed gravity field in the Bouguer reduction (left) and 3D model of the field of the module of the horizontal gravity gradient (right).*

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